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(ENGLAND) J H WILKIN 29 JUL 86 DAJA45-84-M-0452

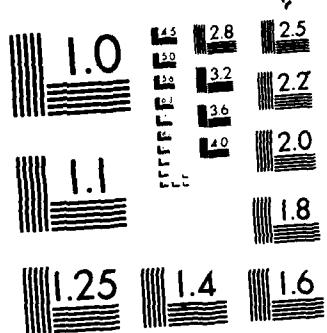
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THE MEASUREMENT OF THE LONGITUDINAL OFFSET
OF THE
CENTRE OF MASS OF CHAFF DIPOLES

FINAL TECHNICAL REPORT

by

JOHN H. WILKIN

JULY 1986

United States Army
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ABSTRACT

The distance between the centre of mass and the mid-point of aluminised glass chaff dipoles, otherwise known as the longitudinal offset, can influence the flight characteristics of the dipoles. Measurements were made of the longitudinal offset of chaff dipoles by encapsulating them in resin and taking multiple sections, measuring the area of the dipoles and the distance between sections. The position of the centre of mass was determined by taking moments of the elemental volumes so described about one end of each dipole. The measurements were made by photomicrography and manual analysis of the film since the characteristics of packed dipoles put the measurements outside the capabilities of computer based image analysers. The final result was that the offset was very small.

Keywords: *infrared*

Radar, passive countermeasures, chaff, aluminised glass, dipoles
dipole aerodynamics, dipole flight, centre of mass.

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THE MEASUREMENT OF THE LONGITUDINAL OFFSET
OF THE
CENTRE OF MASS OF CHAFF DIPOLES

INTRODUCTION AND OBJECTIVES

Chaff, the passive countermeasure employed for the confusion of radars, consists of very large numbers of aluminised glass filaments. They are cut to specific lengths typically between 5mm and 50mm according to the frequency of the radar to be defeated although the most common length used is around 15mm. After they have been cut to length the filaments are referred to as dipoles.

They are made of borosilicate glass filament coated with commercially pure aluminium and the final outer diameter is nominally 0.025mm (0.001in). A cross section of a filament reveals that both the glass and the outside of the aluminium are approximately circular but the aluminium is rarely concentric with the glass. The glass is reasonably constant in diameter but the diameter of the aluminium varies along the length of the dipole. The direction of the eccentricity of the aluminium surface relative to that of the glass also varies along the length of the dipole. Both of these characteristics are apparently random in their variation.

The geometry of dipoles is therefore such as to indicate that the centre of mass, or the position of the centre of gravity, may not be located at the mid point of the dipole's length.

There has been debate on the angle to the horizontal at which the dipoles fly when they are deployed in the atmosphere. A mathematical analysis underway elsewhere at present aims to predict the flight angle in typical operational conditions. That work has shown that the position of the centre of mass of the dipole, is one of the currently unknown factors which would have a major influence on the flight angle if it was not located at the mid point of the dipole. A measurement of the offset of the centre of mass from the mid point of the dipole, otherwise known as the longitudinal offset of the centre of mass, was therefore needed. That measurement is the subject of the work described in this report.

Since the dipole is made of two different materials which are eccentric there is probably a lateral offset of the centre of mass. This topic was not investigated during these measurements because the density of glass and aluminium are very similar and the lateral dimensions are very small compared with the dipole length which means that any lateral offset should be negligible in its effect.

Chaff dipoles are known to be so very variable in most other respects that it was necessary to measure hundreds of dipoles to be sure that a

realistic estimate was obtained of the position of the centre of mass. There are two chaff manufacturers in the USA, so it was also necessary to compare material from both of them. The net effect was that a large number of measurements were needed. The offset was measured in more than two thousand aluminised glass dipoles in total, about half from each manufacturer.

However, there were two major pieces of experimental work which had to be undertaken before the project was brought to a successful conclusion. Both of these are described in the text below.

A somewhat innovative approach was used with the intention of completing the measurements using a computer controlled image analyser. In the event the analyser was not able to handle the problem due to a characteristic of chaff dipoles caused by the way they are typically packed and the work was completed by manual analysis.

METHOD OF MEASUREMENT

The principle of the measurement method is to determine the diameter of the aluminium coating of the dipole at known points along its length, each a small distance apart, and compute the cross sectional area at each. Knowing the area at each section and the distance between sections, the volume and the weights of the individual elements between sections can be calculated. This will also provide the total weight between the first and last section enabling moments to be taken about a convenient point to give the position of the centre of mass and the magnitude of the offset.

The method can be extended by taking a slice perpendicularly through a bundle of parallel dipoles and measuring a large number of dipole areas. If further contiguous slices are taken, each of known thickness, the same principle as used above can be applied to as many dipoles as desired. It is necessary to correlate the individual measurements of cross sectional area for each dipole of course. This entails placing markers of some form on, or rather in, each slice.

Chaff filaments are always packed parallel to each other during manufacture and the bundle of filaments is then cut, perpendicular to the filaments, to produce a pack of resonant dipoles. So taking slices perpendicularly through filaments is a common occurrence.

However glass filaments are actually fractured and broken rather than cut during the industrial 'cutting' process which produces dipole packs. This produces a jagged edge on the end of each dipole which is quite unsuitable for area measurement. The way over that problem is to encapsulate the pack of dipoles in resin so that the dipoles are held firmly while they are cut. However, it is still necessary to grind and polish the cut surface to get a suitable image for measurement.

Since dipoles are about 25 micron diameter the measurement has to be done by photography through a microscope and then with some form of analysis of the photographic images. The photomicrography was the most straightforward part of this project.

Taking slices of encapsulated chaff packs certainly enables the characteristics of large numbers of filaments to be measured and the process can be tightly controlled, as detailed below.

THE PRACTICAL METHOD

There are two manufacturers of aluminised glass chaff in the USA and both use the same basic manufacturing process. In that process aluminised glass is produced as a continuous filament and is wound on to a drum at the conclusion of the process. Periodically the drum is stopped and a cut made through the filament on one drum radius to give a hank of filaments. The hank is about 1.5m long, that is, the drum's circumference.

Two sample hanks were obtained from Lundy and two from Tracor, the two manufacturers, and two packs of chaff were cut from each hank of sufficient length for the measurements to be made over 15mm of hank length in each pack. Since the filament is formed in manufacture and wound on to the drum in a continuous process there was no point in taking more than two samples per hank.

The practical method which was used to measure the offset took the total of eight, by now typical, packs of chaff and positioned markers in them, before encapsulation, to identify the location of the area to be photographed during the later photographic stage.

The eight packs of dipoles were then individually encapsulated in resin in a cylindrical mould with the dipoles parallel to the axis of the mould. A metal insert which was screw threaded internally was incorporated into the moulding but there was no contact between the insert and the dipoles.

When the resin had been cured the cylindrical encapsulants had their ends trimmed on a lathe so that they were true cylinders with parallel and flat end surfaces.

A thick circular aluminium plate was machined so that both of its 'flat' surfaces were actually flat, as well as being parallel and true when mounted in the chuck of the lathe. It was drilled with eight holes at a constant radius and the eight encapsulated samples were mounted on it using bolts through the plate and into the insert in the moulding. The plate was repositioned in the lathe chuck and the flat surface of all of the samples was machined until excess resin had been removed and the ends of the chaff dipoles were exposed. The plate with the eight samples mounted on it is illustrated in Figure 1.

The plate with the samples still attached was removed from the lathe and mounted on a lapping machine. The cut surfaces of the samples were then ground flat and polished so that the cross sections of a large number of dipoles could be seen under a microscope.

The samples were never removed from the plate during this, or the rest of the subsequent work, so any further mention of the plate or the

samples refers to the same thing.

The plate with its samples was washed and dried and placed in a jig under a microscope. The jig enabled the plate to be rotated about its centre so that the eight polished surfaces could be sequentially positioned under the microscope lens. An area containing approximately 300 dipoles was photographed in each of the eight sample packs.

Each sample contained approximately 750,000 dipole so finding the same 300 dipoles was no easy matter, the use of markers was crucial in locating the area. This topic is dealt with more fully below. For the present it is sufficient to note that the marker in each of the eight samples had to be positioned at the same radius from the centre of the metal plate to have any hope of finding the area quickly.

After all eight were photographed under the microscope the plate of encapsulated samples was again turned on the lathe and the dipole length reduced that is, a slice of the same thickness was machined off all of the sample chaff packs. The surface was reground, polished and photographed to show the cross sections further along the length of the dipoles. The thickness of the slice taken (the amount turned off), was measured. The process was repeated more than 30 times through the chaff packs giving a series of photographs of the cross sections at known points along the dipoles.

The resultant 240 photographs were to be examined by an image analyser to measure the cross sectional area of 300 dipoles in each photograph, a total of 72,000 measurements. However this did not prove possible and the analysis was completed manually as described below.

The encapsulation, sectioning, grinding, polishing and photomicrographic techniques have been used for a number of years in laboratory chaff studies and are, taken together, a well established method of examining dipoles while still in the pack. The only difference in the work reported here is that the contiguous slice technique had not been employed before in chaff investigation but it is not new in other branches of photomicrography.

The description of the method used for the measurements has summarised rather than given a sequential account of the work. This has been done for clarity but there were two substantial areas of experimental work which were needed to solve problems encountered in the initial attempts at the measurement. The first, and by far the major part of the early work, involved developing a method whereby it was certain that the same dipoles were photographed in each slice. These experiments are described in the next section. The second problem area was in developing the process for preparing the surfaces of the samples to the high standards of quality necessary for the photographic stage. That work is described under Sample Preparation below.

MARKERS - KEEPING TRACK OF DIPOLES

There are about 750,000 dipoles in each sample and it was necessary to select an area containing 300 dipoles and then be able to find the same

300 dipoles each time the sample was placed under the microscope after each of the 30 slices. But most dipoles look alike and the 300 dipoles can only be identified when they are individually labelled during the analysis. So it was necessary to place a marker in the sample to signpost the area where the 300 dipoles were.

Markers on the outside of the pack did not permit adequate identification but after a number of experiments with markers in the pack a method was developed to insert a strand of very thin copper wire which was parallel to the dipoles, without distorting them, and which signposted the area to be photographed. Under the microscope the edge of the copper wire marker was placed in the middle of one of the long sides of the rectangle of the viewing area as seen by the camera and therefore appeared in that position in the photograph.

The area to be photographed was very small and a positioning error of as little as 0.001in. could have meant a loss of 10% of the dipoles from the field of view for each photograph. This would have been unacceptable if it had happened each time in the 30 photograph sequence. Consequently a second reference mark was needed to prevent the photographic field of view rotating by even a few degrees about the copper marker.

The requirements outlined in the previous paragraphs were not known or logically deduced but painstakingly discovered by trying to follow dipoles in the first few sections which were taken.

The first marker was reasonably straightforward but the second one was rather more of a problem. A number of methods were tried and the one which was eventually arrived at was to machine a flat surface on the side of the pack of dipoles, parallel to the dipoles, after the pack had been encapsulated in resin. Under the microscope the flat surface was seen end-on and appeared as a straight line. The pack was then encapsulated a second time to preserve the straight line of the flat surface during the grinding operations which followed each of the 30 sections.

In operation, the photographic viewing area, the frame, was positioned so that the side of the frame which contained the copper wire marker was parallel to the straight line. The angle between the sample and the photographic frame was maintained throughout all 30 photographs in this way. This was the easiest way to overcome the problem because the jig which held the sample plate was itself held in the microscope stage, a device which could move the sample plate in an X and a Y direction under vernier control. Positioning the frame and the straight line from the cut edge of the sample in the X direction made subsequent manipulation to find the copper wire marker very easy. When found it was simply positioned in the middle of the top of the frame and the photograph taken.

The straight line from the machined flat surface can be seen in Figure 1 as can the effects of the re-encapsulation.

The use of the markers described above still enabled the position of the area of the sample which was photographed to move slightly from frame to

frame. It was very little but to compensate for this dipoles close to the edge of the frame were not used when choosing which dipoles to measure in the final analysis. In other words, since each frame contained about 400 dipoles and only 300 were to be measured a band of dipoles around the edge of the frame was left unmeasured throughout the measurement sequence to compensate for the slight movement of the frame.

SAMPLE PREPARATION

At the same time as the operational problems of following the 300 dipoles from slice to slice were being solved it became apparent that the quality of the polished surface of the sample had to be improved beyond what had been the accepted standard before this work.

Generally all of the processes to prepare the sample for photography, that is, machining away the bulk of the slice, grinding the surface so that it was flat and the polishing sequence, had to be tailored to the needs of the image analyser. The reason was that minute flaws measuring as small as 0.001in. across were treated as additional dipoles by the image analyser. If the flaw was next to the dipole its area was added to that of the dipole and if the flaw touched two dipoles, a scratch for instance, then the analyser result was meaningless.

The methods of achieving the improvements were by a logical straightforward development; in essence by taking much more care over each of the preparation steps. No additional research work was necessary.

The sequence of grinding abrasives was carefully examined. The unnecessarily coarse ones which had given long lasting scratches were replaced and some of the intermediate grades were changed so as to achieve the best surface quality. The polishing stages which used several different grades of diamond compound were considerably refined in a similar way. Abrasives were only part of the answer though, other factors considered and modified were lubricants, cutting speeds and substrates as well as the ways in which the samples were held during the processing stages.

Preparing the samples was complicated by the combination of the relatively hard glass in the dipoles and the very soft aluminium coating and resin in which the dipoles were embedded. This caused a preferential removal and smearing of the softer constituents over the surface with an apparent increase in the area of the dipoles. The problem was solved by using alternative substrates on which the samples were polished.

Parallelism of the polished surfaces between slices was important in this application. This was maintained by a combination of making special jigs to hold the samples during the machining, grinding and polishing sequences, by developing the machining methods and generally taking a lot of care in all of the stages.

Developing the methods to provide the high surface quality itself generated a further problem because high quality can only be achieved in

a much longer preparation time. With 240 slices to be prepared the time for each had to be reduced as much as possible. This was done by preparing initially four, and as experience built up all eight samples at once.

It was further reduced by restricting the area of each sample to a minimum so that less material had to be ground away and less unnecessary surface area polished for each slice. This can also be seen in Figure 1 as the black segment on the surface of each sample and particularly on the sample next to the one labelled 12. The segment is bounded by the straight line of the machined flat surface seen end on, the two small curves which come from the curved surface of the sample before the second encapsulation and finally the curve opposite the straight line. That was produced when all of the sample surface from that radius inwards was turned off (or relieved) on the lathe so that only the area of segment which contained the copper marker needed to be polished each time.

All of the enhancements in the overall preparation technique worked well, they just took time to develop.

PHOTOMICROGRAPHY

After the extensive difficulties in the preparation of the samples the actual photography on the microscope went particularly well and there were no problems in that part of the work. Previous experience with illumination of encapsulated samples and methods of achieving the exact magnification on the film helped make the photography the easiest part of the project.

The microscope used was an Olympus BH2 which is a standard metallurgical laboratory system microscope. Illumination was through the lens of the microscope. The camera was a Canon Fl which is a standard professional 35mm system camera. Sufficient components were taken from both systems to do this particular job. There was nothing unusual about the final arrangement, the same combination could be found in use in any small metallurgical laboratory. Similarly the grinding and polishing machines and materials were standard metallurgical items. There is therefore no reason to describe any of them in detail.

The film used was Ilford FP4 rated at 125 ASA. All photographs were in black and white. This type of film was used because definition and contrast are better than can be obtained from colour film. The samples were also in black and white.

Figure 2 is a typical photomicrograph from the full sequence. The copper marker can be seen as the white segment of a circle in the top edge of the photograph. The aluminium coating on the dipoles appears as the white circular rings or part rings of crescent shape for those dipoles which were not completely coated with aluminium. Part coating is a characteristic of chaff dipoles and can be controlled by quality assurance procedures. The glass cores of the dipoles appear as the black circles in the middle of the white rings or on the inside of the crescents. The resin in which the dipoles were embedded also appears

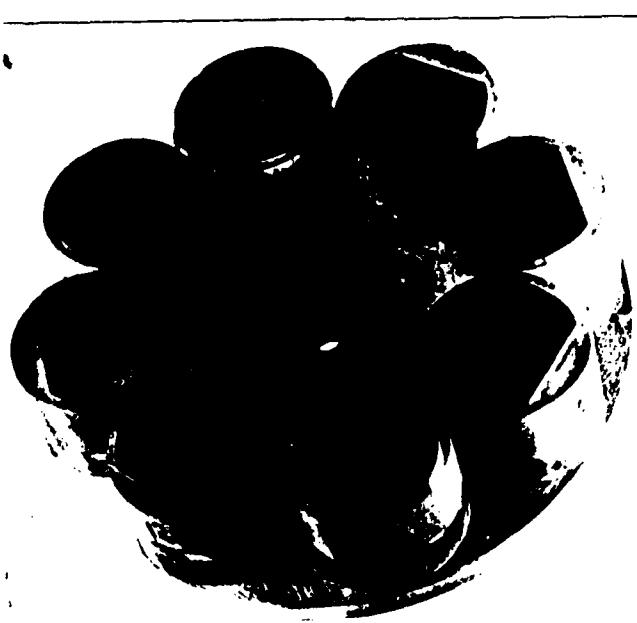


FIGURE 1 - THE SAMPLE PLATE

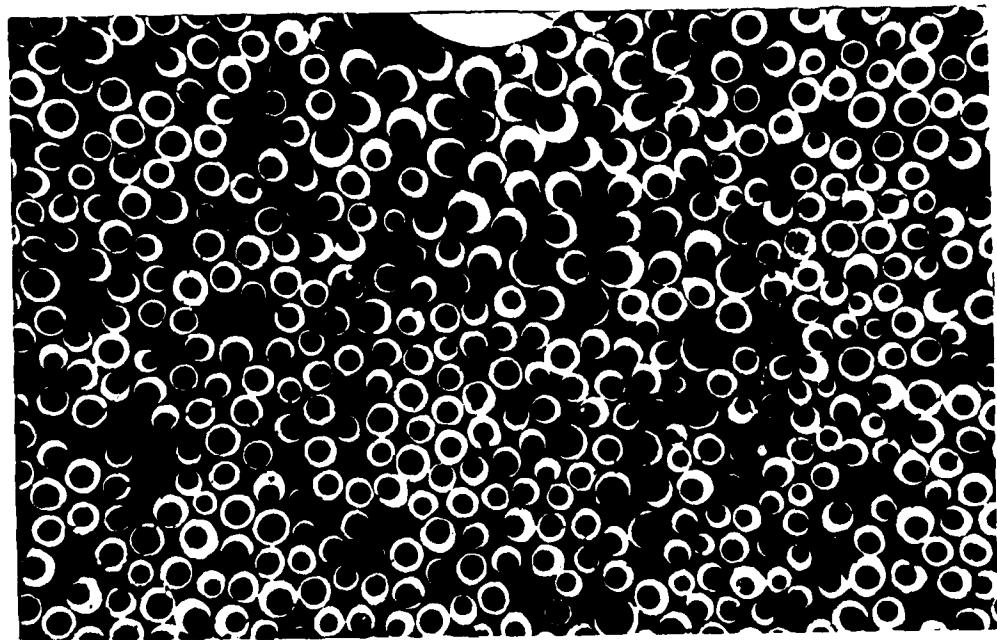


FIGURE 2 - A TYPICAL PHOTOMICROGRAPH

black so the junction between the resin and the glass is not readily apparent. Unmetallised glass cores do occur but where a white crescent appears there is a glass core attached, the aluminium cannot appear by itself.

To return to the measurement work, all of the photographs were taken, developed and examined by projection. They were proven to be of good quality and ready for analysis.

IMAGE ANALYSIS

The image analyser which was to be used to measure the area of the dipoles is really a video camera linked to a minicomputer. The principle of operation is that the video camera converts the photomicrographs into a video image and the computer then counts the number of pixels in the image of the dipole section to measure its area.

The aluminium coating of the dipole normally appears white whereas the glass core and the background resin both appear black in the image, as seen in Figure 2. The minicomputer could be programmed to fill-in the core so that it appeared white, the same as the aluminium.

However, the analyser could not fill in the glass core of those dipoles which were only partly coated with aluminium since it didn't know where the dipole's curved surface was and couldn't distinguish between the glass core and the encapsulating resin, both appeared black. This can be overcome by using a light pen but it is surprisingly time consuming. A quicker method is by drawing a line on the photograph to complete the circumference of the dipole; visually it is generally clear where the line should be. Using this method, or pigmented resin to provide a differential contrast in any future application, would enable the analyser to measure any single photograph

So by using the built in facilities of the analyser most of the minor difficulties could be overcome but there was one major one which could not be overcome. It is of course necessary to relate the individual area measurements for each dipole, that is from one photograph to the next in the slice sequence. This was the research part of the work, in that it had not been done before, but as usual chaff came up with something unexpected with the effect that the analyser was not able to follow the individual dipoles.

The reason, which is, in its own small way, new knowledge, is that dipoles do not stay in the same place from one photograph to the next. Almost every dipole in the field of view moves about half a dipole diameter and randomly in direction at each slice step. This was taking a slice as small as 0.25mm. The reason can be traced to the random changes in diameter and the eccentricity of the aluminium coating along the length of the dipole. The effect is that an individual dipole, at one cross sectional slice, is pushed by the high points of its neighbours and moves in a direction determined by the resultant force. Since the high points are random the direction and the final position is random in the next slice.

If the photographs are viewed in sequence, like a movie film, then there is the visual effect of a jitter in the position of each individual dipole. Rather like a poorly made cartoon.

There were two other characteristics evident, superimposed on the random "jitter" of the dipoles as the series of slice photographs progressed. One was a bulk movement of groups of about 50 dipoles which "swirled" but stayed within the photographic frame and the other was of individual dipoles which travelled rapidly across and out of the frame. It was not feasible to investigate these characteristics further in the time available.

It was clear that dipoles were not nicely parallel to each other as had been previously assumed. Some movement would be expected from the way that dipoles are wound on the drum during manufacture, then taken off, cut and packed. But the detail movement of the dipoles over a distance as small as 0.25mm was not known nor expected.

These characteristics could be important since if the dipoles are not parallel they are tending to tangle. If they are tangled while still in the pack they will tangle further as they are operationally dispensed in the atmosphere (they can't reasonably be expected to separate better than parallel dipoles), so 'birdnesting' will be increased and efficiency reduced.

The image analyser could readily display any of the modified photographs, measure the dipole areas, assign numerical markers to the individual dipoles and retain those markers on the screen when the first photograph was removed. However it could not use the retained markers and relocate them on the correct dipoles when the next photograph was displayed because of the random movement of the dipoles.

The original slice thickness of 0.5mm was reduced down to 0.25mm early on in an attempt to follow the dipoles but the basic problem remained. (The movement of half a dipole width was after the slice thickness had been reduced; the movement was greater when thicker slices were taken.)

MANUAL ANALYSIS

Having reached an apparent impasse with the image analyser a manual method of analysis was set up to obtain measurements of the samples. In effect a visual process was developed to compensate for the jitter and the dipole travel between any two adjacent photographs. The visual process also ensured that the same dipole was being labelled with the same marker each time. It also needed to be, and was, a method of quickly following and measuring the dipoles.

The method used was to take a conventional 35mm projector and modify it by mounting a high quality 50mm focal length enlarging lens on it. This gave the highest definition image available projected over a short distance of about 1 metre. The projector was mounted vertically so that the image could be displayed on a horizontal bench surface. A photographic enlarger could not provide the film handling speed nor the image intensity which was necessary.

A thin steel sheet was placed on the bench and covered with white paper to receive the projected image. Three hundred numbered magnetic markers were then placed on the paper at the projected dipole positions. With the dipoles individually labelled by the numbered markers, they were measured and the diameter recorded against the dipole's number. When the next photograph was projected the steel sheet with the markers still in position was moved as a unit and repositioned to get the best match with the new projected image. The steel sheet was secured to the bench and the individual markers moved to the new positions of the dipoles.

The method of tracking dipoles from frame to frame was to use one of the natural characteristics of dipoles. What was needed was some natural markers within the frame which would signpost how the dipoles were moving. Although the glass filament in the centre of aluminised glass is of a constant diameter along the length of an individual dipole there is some variation from one dipole to the next and there are extremes in this variation. Whereas dipoles tend to look alike with the most notable variation being the outer diameter of the aluminium, upon closer inspection the very large and very small diameter glass cores become apparent. Obviously the outer diameter of the aluminium cannot be used as a marker but the large or small glass cores can be and were in these measurements.

The way of doing this was to put specific magnetic markers on the steel sheet to locate the positions of the very large and the very small cores in the first frame which was projected. When the next frame in the series was projected the steel sheet was moved to match up the copper marker position, this was a coarse match. The sheet was then adjusted to get the best match for the positions of the large and small cores, this was a sort of 'fine tuning' of the matching process.

There was a rather strange visual integration effect which took place during the fine tuning because the correct position would suddenly become visually apparent, rather like a camera suddenly coming into focus. At that point it was clear just which dipoles had moved and in which directions. The markers for all of the dipoles were then adjusted to their new positions and the measurement of the dipole diameters in the new frame went ahead.

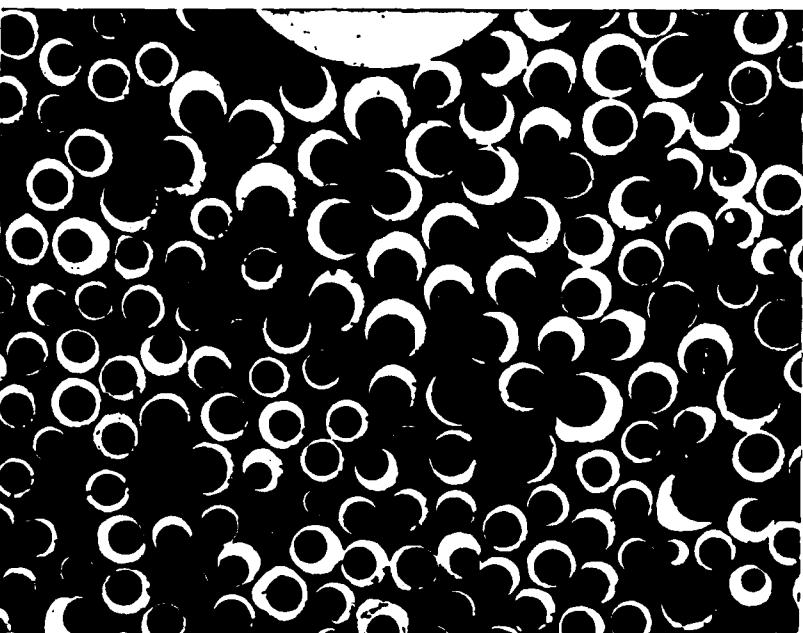
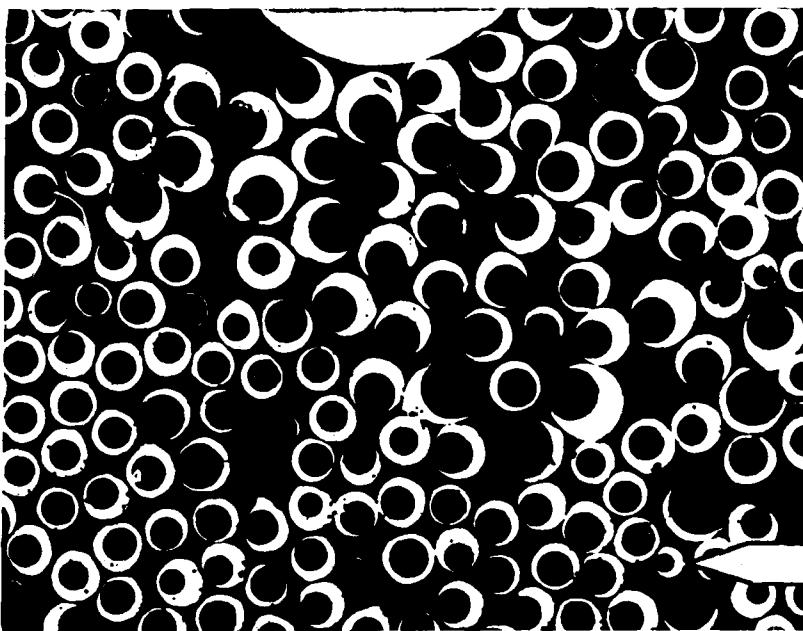
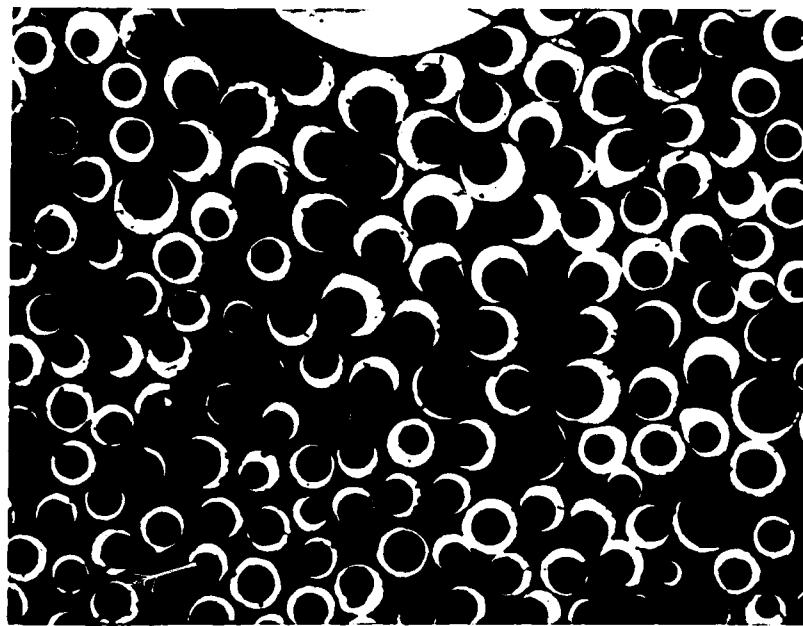
Three contiguous photographs from one of the sequences are reproduced in Figure 3. The first one is the same photograph as was used in Figure 2 but somewhat enlarged to show the dipoles more clearly. They can be correlated using the unusual dipole, the only one which is not circular or crescent shaped, just to the left and slightly above the centre of Figure 2

A large core and a small core have been identified in Figure 3 as examples of how they can be used as natural markers from one slice to the next. There are several other large cores and one or two other small ones which could also have been used in Figure 3.

The method of measurement was by use of a cursor of two divergent lines engraved on a transparent acrylic sheet and calibrated so that it could be easily read. A numeric keypad from a computer keyboard was

FIGURE 3

THREE CONTIGUOUS SECTIONS



incorporated into the handle of the cursor so that the reading could be entered into a computer. A modified cursor was developed to put the data directly into the computer without the necessity of reading it but the measurements were completed before the new cursor was ready.

The method was tedious in that it entailed some 8000 measurements but it was not difficult. It has provided centre of mass measurements for the samples.

Several simple computer programs were written to accept the dipole diameters in each slice as input, calculate the areas and the elemental weights, correlate the elements for each dipole, take moments, calculate the offset and finally print out the results in the form of a table.

Histograms were drawn from the results of the measurements which were taken and they have been incorporated into the next section of this report.

RESULTS

The histograms are given in Figure 4 and 5. Each contains the measurements of the offset of the centre of mass for the 300 dipoles assessed in each of the samples. The offset is the distance of the actual centre of mass from the mid point of the dipole and was measured in microns.

The offset is plotted along the horizontal axis in intervals of 50 microns. The number of dipoles recorded in each interval is plotted on the vertical axis. The same scales have been used for all eight of the histograms.

The measurements were made over a total dipole length of 7.75mm as a result of reducing the slice thickness to 0.25mm. Therefore a second offset scale, in percent of dipole length, has been drawn parallel to the one in microns for easier assessment of the histograms.

Both of the chaff manufacturers in the USA are represented in the results, the first four plots, that is Figure 4, are for the Lundy samples and the following four (Figure 5) are for the Tracor samples. Each of the plots has been marked with the respective manufacturer.

The sample number given on each of the histograms was used throughout the experimental and measurement work as an arbitrary reference for the sample. This was done in preference to using hank numbers or manufacturer's names and so enabled the samples to be treated completely impartially. The numbers have no other significance.

CONCLUSION

A method was developed in this work to measure the offset in the position of the centre of mass from the mid-point of aluminised glass chaff dipoles. A total of just over 2000 dipoles were measured and the

results presented in the form of a set of histograms.

All of the histograms have a very similar shape and all show that the offset is very small, in practical terms less than about two percent of the dipole length.

Chaff from the two manufacturers in the USA was measured but the results show that there was no significant difference between them, at least as far as the position of the centre of mass is concerned.

There was considerable evidence that there was tangling between the dipoles in the sample chaff packs since the dipoles were clearly not parallel to each other even over a distance as short as 0.25mm. The relative movement between the dipoles caused major difficulties in making the offset measurements. The tangling would be expected to promote birdnesting when the dipoles were dispensed in the atmosphere and thereby reduce the efficiency of the chaff packs.

THE MEASUREMENT OF THE LONGITUDINAL OFFSET

OF THE

CENTRE OF MASS OF CHAFF DIPOLES

FIGURE 4

NUMBER
OF
DIPOLES

150

50

0

SAMPLE 9 - LUNDY

OFFSET

0 100 200 300 400 500 600 Microns

0 1 2 3 4 5 6 7 8 Percent

NUMBER
OF
DIPOLES

150

50

0

SAMPLE 7 - LUNDY

OFFSET

0 100 200 300 400 500 600 Microns

0 1 2 3 4 5 6 7 8 Percent

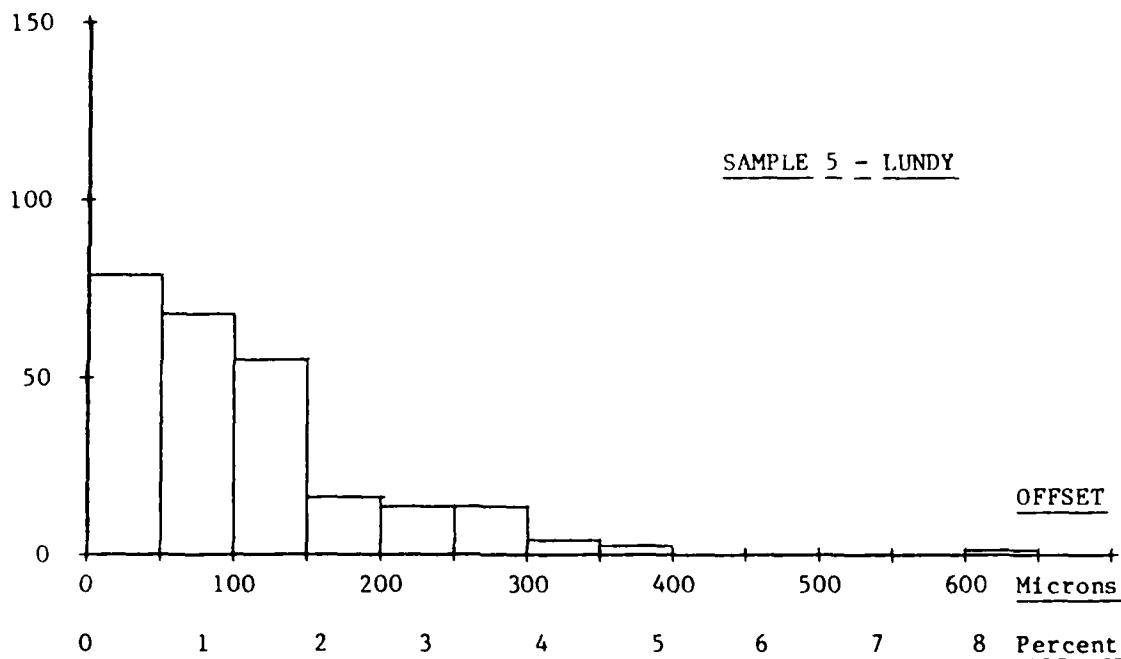
THE MEASUREMENT OF THE LONGITUDINAL OFFSET

OF THE

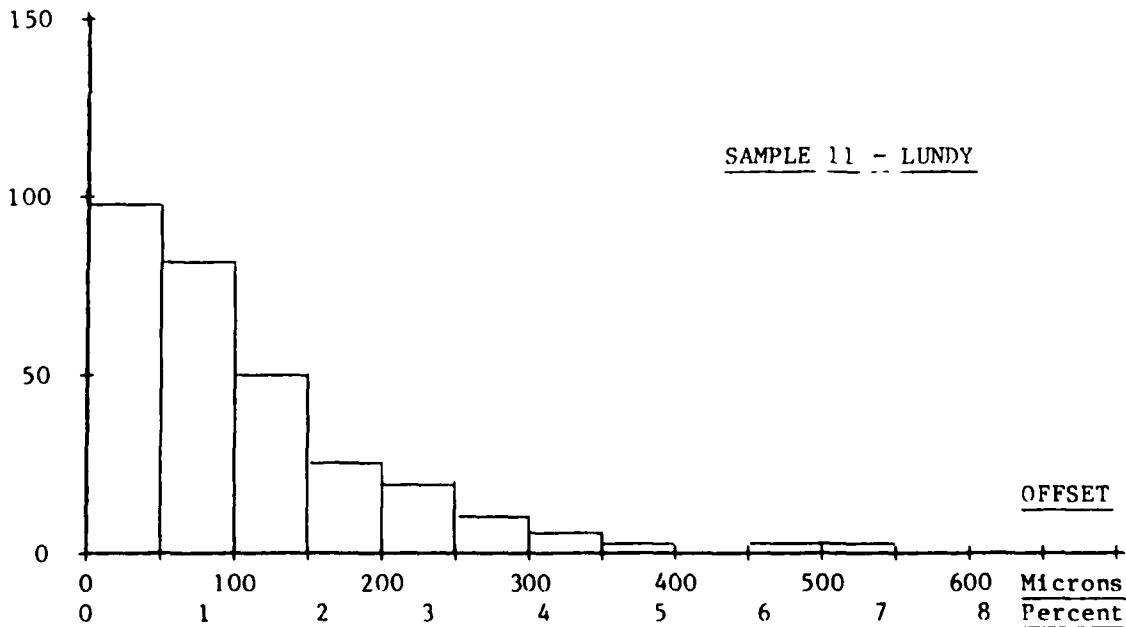
CENTRE OF MASS OF CHAFF DIPOLES

FIGURE 4

NUMBER
OF
DIPOLES



NUMBER
OF
DIPOLES



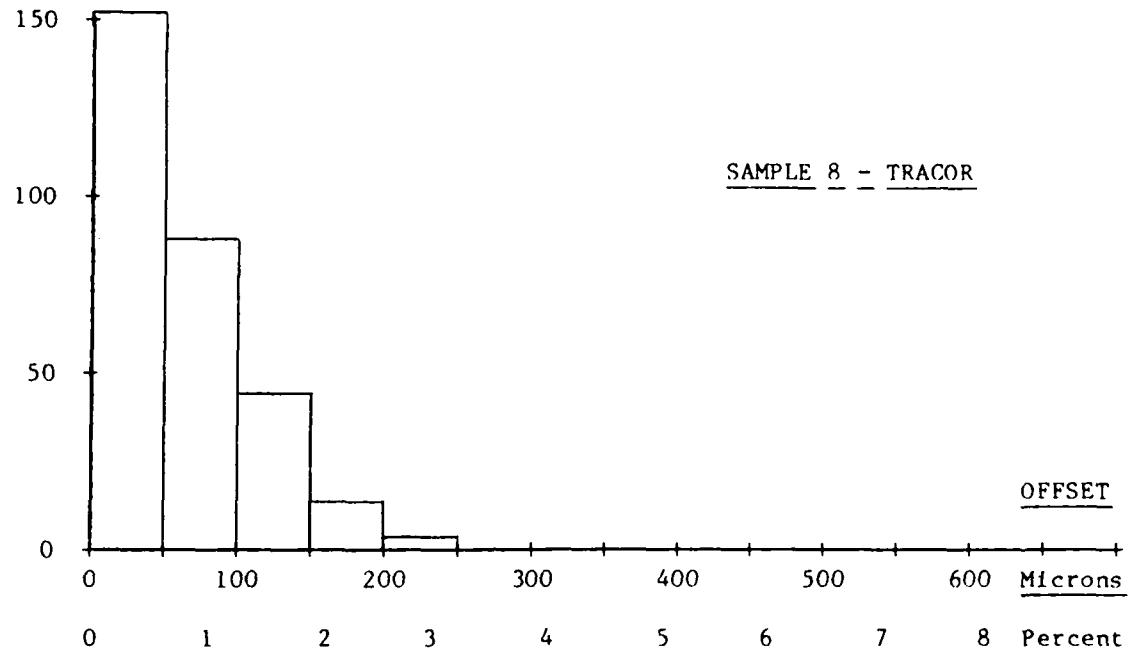
THE MEASUREMENT OF THE LONGITUDINAL OFFSET

OF THE

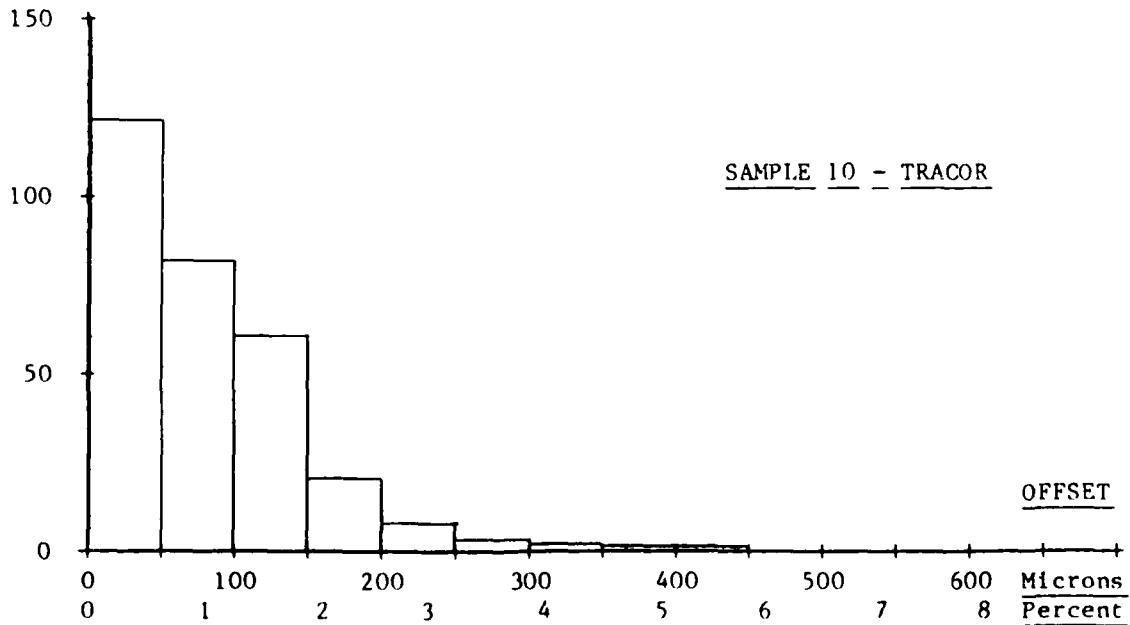
CENTRE OF MASS OF CHAFF DIPOLES

FIGURE 5

NUMBER
OF
DIPOLES



NUMBER
OF
DIPOLES



THE MEASUREMENT OF THE LONGITUDINAL OFFSET

OF THE

CENTRE OF MASS OF CHAFF DIPOLES

FIGURE 5

